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**Editors:  
Brian D. Warner  
Jerry Foote  
David A. Kenyon  
Dale Mais**

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# BVRI CCD Photometry of Theta-1 Orionis A

Jeffrey L. Hopkins  
 Hopkins Phoenix Observatory  
 7812 West Clayton Drive  
 Phoenix, Arizona 85033-2439  
 phxjeff@hposoft.com

Gene A. Lucas  
 NiteOwl Astrophysical Observatory  
 15640 East Cholla Drive  
 Fountain Hills, Arizona 85268-4357  
 geneluca@ix.netcom.com

## Abstract

Time-series BVRI CCD photometry data on Theta-1 Orionis A (V1016 ORI), a member of the familiar Trapezium cluster, was obtained at the Hopkins Phoenix Observatory (Phoenix, AZ) during December 2006 through February 2007. Data was acquired during two primary eclipse cycles, along with multiple out-of-eclipse observations. The observations were made with a Meade DSI Pro CCD camera and LX200 GPS 12 inch (30.5 cm) aperture telescope equipped with Johnson-Cousins filters. This paper details the observing setup, the technique, and resulting data analysis. It was noted that the estimated mid-eclipse (minimum light) point during the 02 December 2006 primary eclipse appears to have occurred several hours later than predicted from the early epoch timings. The possible secondary eclipse (which has evidently never been observed by anyone) proved to be elusive.

## 1. Introduction

Located in the great Orion Nebula M42, Theta-1 Orionis (more commonly known as the Trapezium) consists of several stars, the four most prominent of which form a trapezoidal geometric shape. These stars are labeled A, B, C, and D (not in order of brightness). The E and F stars do not appear in our images. Theta-1 Orionis A (V1016 Ori) is the star system of interest in this project. Theta-2 Orionis is a double star located some 100 arc seconds southwest of Theta-1. Figure 1 shows diagrams of the star locations.

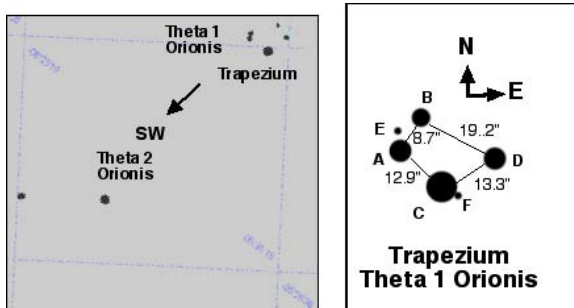


Figure 1. Theta-1 and Theta-2 Orionis Locations.

Theta-1 Orionis A and B are eclipsing binary star systems with accepted periods of 65.43233 and

6.470525 days, respectively. The other eclipsing binary system, Theta-1 Orionis B (BM Orionis) appears in the same images, so data on it were taken, too. These data may be used for another project on just that star system.

In early 1975, Lohsen (1975) was the first to report Theta-1 Orionis A as variable. The original period was determined to be 196.25 days. A few months later Strand (1975) reported a period of 196.298 days. In the spring of 1976 Lohsen (1976a) reported a refined period of 196.297 days. To add to the confusion, in December 1976, Lohsen (1976b) reported spectroscopic data suggesting a period of 392.594 days. In November 1976, Baldwin (1976) of the AAVSO, reported a period of 65.43 days, or one-third that of other reported periods. In May 1977, Franz (1976) confirmed the new period and refined it to 65.4325 days. In January 1982, Sowell and Hall (1982) reported a still finer period of 65.43233 days with an epoch of JD(hel.) 2,443,144.600. Robertson et. al. (2002) reported a possible secondary eclipse around phase = 0.58, with the possibility of the secondary event occurring between phase = 0.3 and 0.7. To date, no one has reported a definite secondary eclipse.

## 2. Published Data

The published data for the main Theta-1 Orionis stars is listed below:

### Theta-1 Orionis A (V1016 Ori)

Alt des. HD37020, HR1893  
Period, d 65.43233  
V Magn. 6.72 to 7.65 (20 hours duration)\*  
(Suspected secondary eclipse at phase 0.3 to 0.7)  
\* Epoch = 2,443,144.600 (AAVSO)  
\* Epoch = 2,452,501.5000 (SIMBAD)  
167 cycles = 10,861.76678 d  
U = 5.87 B = 6.72 V = 6.72 R = 6.41 I = 6.20  
Prim. Eclipse (AAVSO) JD 2,454,071.410 - 1 Dec 2006; JD 2,454,136.840 - 5 February 2007  
Prim. Eclipse (SIMBAD) JD 2,454,071.8872 - 2 Dec 2006; JD 2,454,137.3200 - 5 February 2007

### Theta-1 Orionis B (BM Ori)

Alt des. HD37021, HR1894  
Period, d 6.5470525  
V Magn. 7.96 to 8.65  
U = ? B = 8.20 V = 7.96 R = ? I = ?

### Theta-1 Orionis C (For reference only)

Alt des. HD37022, HR1895  
U = 4.188 B = 5.140 V = 5.134 R = 4.914 I = 4.734

### Theta-1 Orionis D (Used as Comparison Star)

Alt des. HD37023, HR1893  
U = 5.96 B = 6.78 V = 6.70 R = 6.41 I = 6.22

## 3. HPO Equipment

BVRI CCD photometry was performed at the Hopkins Phoenix Observatory (HPO) in Phoenix, Arizona on multiple nights during the December through February 2007 observing season. A Meade® 12 inch (30.5 cm) aperture LX200 GPS telescope (Figure 2) was used at f:10 with a modified Meade Deep Sky Imager™ Pro (DSI Pro) monochrome CCD camera, equipped with an ATIK filter wheel and standard Johnson-Cousins BVRI filters. The Meade Autostar Suite™ software was used for image acquisition and subsequent processing. Data analysis was performed with FileMaker Pro database software.

## 4. Observing Technique

CCD photometry of the Trapezium star system is interesting, and provides some challenges. The stars are easy to find, and the two variables plus a good comparison star (star "D") are close together. At the same time, however, photometry of the Theta-1 Orionis stars proves difficult. This is due to the presence of background nebulosity, and the brightness and

close spacing of the stars of interest. (theta-1 A and B are separated by less than 9 arc seconds.)



Figure 1. Hopkins Phoenix Observatory BVRI Equipment.

Single-channel photometry requires special techniques and is especially difficult. CCD photometry has proven to be a bit easier. The star images tend to become "bloated" at times, but good data can still be extracted from the images. With the setup at HPO, it was found that exposures between 0.5 and 4.0 seconds produced acceptable data. Data were taken with exposures of 0.5 seconds during November-December 2006 and 4.0 seconds during the February 2007 observations. The images were stored as FITS files. It appears the data from the 0.5-second exposures were more consistent than the longer exposures. The weather at this time in Phoenix approached freezing during the evenings.

A typical sequence was to start with the blue (B) filter and take approximately 10 images. These images were aligned and stacked (combined) by the Autostar-Envisage software. Three sets of stacked images were taken for each filter. The procedure was then repeated throughout the night. Each sequence (BVRI) took approximately 20 minutes. This seemed to work well. During the 02 December 2006 eclipse,

this resulted in nearly continuous imaging from about 9:30 pm through 3:30 am. Figure 3 shows one of us (Lucas) adjusting the filter prior to starting a new set of images.

Light box flat frames were taken at the end of each observing night. For nights using exposures longer than 1.0 second, dark frames were taken for the selected exposure time, prior to the start of the observations.



Figure 3. Adjusting Filter Wheel.

## 5. Images

Figures 4 and 5 show images taken with the V filter out-of-eclipse and near mid-eclipse.

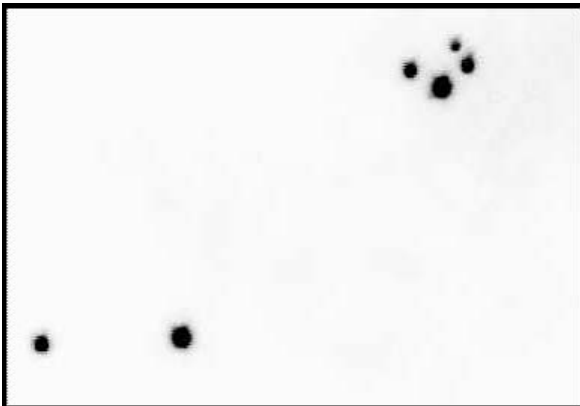


Figure 4. Theta-1 Orionis Out-of-Eclipse 01 Dec 2006 (V Filter).

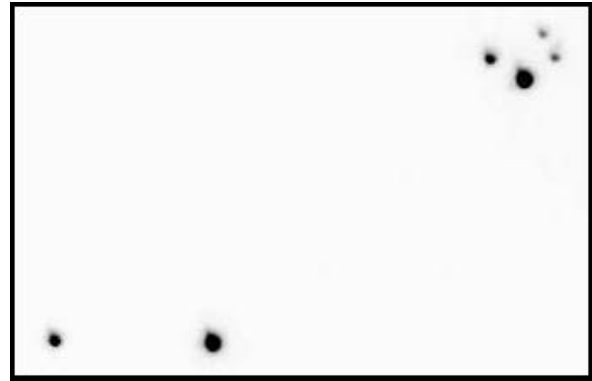


Figure 5. Theta-1 Orionis During Eclipse 02 Dec 2006 (V Filter).

During November - December 2006, a total of 33 images were taken in each filter band (out of eclipse). During the 02 December 2006 primary eclipse, 24 image sets were taken (3 sets of 10 images, stacked, in each filter). Each image (stack) was calibrated using a bias frame and flat field. Because of the short exposures (0.5 seconds), dark frames were not used. During the 05 February 2007 primary eclipse 15 images were taken in each band. Each image was calibrated using a flat frame. All of the 05 February 2007 observations were taken with 4.0 seconds exposure time and a dark frame was subtracted (during imaging).

## 6. Data Reduction

The Meade Autostar-Envisage image processing software was used to calibrate the images and to determine differential magnitudes referenced to Theta-1 Orionis D.

Theta-1 Orionis D Reference Magnitudes  
 B = 6.78    V = 6.70    R = 6.41    I = 6.22

The Meade Autostar image processing software created a data log, listing the times each image was taken, and the raw differential magnitudes determined during calibration, as well as other information. The data log file was then edited, and the raw magnitude data were transferred to a custom FileMaker Pro database program, developed at HPO. Figure 6 shows a sample screen shot of the HPO FileMaker Pro database. The mean time for each filter image set was calculated, as well as the average magnitudes and standard deviations. The Heliocentric Julian Date (HJD) for the observation was also calculated. The data were then exported to a Microsoft Excel spreadsheet and plotted.

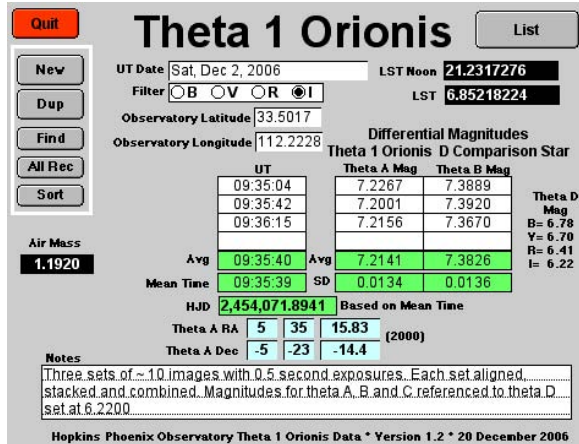


Figure 6. Custom FileMaker Pro Database.

Table 1 lists reduced data from the 02 December 2006 eclipse. (Note: Magnitude data has not been transformed to the standard system.)

B Filter Data		V Filter Data		R Filter Data		I Filter Data	
HJD	Mag	HJD	Mag	HJD	Mag	HJD	Mag
64.76930	6.7107	64.7719	6.7646	64.7739	6.4813	64.7780	6.4048
65.77410	6.7355	65.7756	6.7027	65.7773	6.5068	65.7786	6.4132
66.77003	6.7531	66.7725	6.7172	66.7754	6.4488	66.7770	6.3910
70.77159	6.6939	70.7766	6.7117	70.7783	6.4477	70.7802	6.3439
70.77327	6.6928	70.7835	6.7160	70.7820	6.5078	70.7896	6.3216
70.78521	6.7575	70.7864	6.7735	70.7880	6.4691	70.7994	6.3357
70.79435	6.7718	70.7929	6.7453	70.7914	6.4725	71.7131	6.8469
71.70745	7.2288	70.7959	6.7192	70.7977	6.4698	71.7281	6.9506
71.71631	7.2189	71.7092	7.1869	71.7247	6.9580	71.7451	6.8513
71.73670	7.3332	71.7110	7.2277	71.7426	7.0217	71.7556	6.8794
71.74776	7.3312	71.7197	7.2172	71.7523	7.0271	71.7649	6.9145
71.75894	7.3999	71.7394	7.3036	71.7632	7.0904	71.7734	6.9419
71.76689	7.4419	71.7503	7.3248	71.7706	7.1325	71.7804	6.9697
71.77558	7.4678	71.7608	7.3791	71.7786	7.1397	71.7874	6.9862
71.78231	7.4559	71.7687	7.3858	71.7857	7.1645	71.7962	7.0095
71.79036	7.5172	71.7771	7.4201	71.7940	7.1922	71.8054	7.0330
71.79938	7.5345	71.7840	7.4346	71.8036	7.2119	71.8122	7.0584
71.80724	7.5686	71.7920	7.4617	71.8104	7.2314	71.8194	7.0592
71.81416	7.6116	71.8018	7.4985	71.8178	7.2973	71.8270	7.0782
71.82181	7.6139	71.8087	7.4974	71.8253	7.3159	71.8332	7.0883
71.82891	7.6742	71.8159	7.5798	71.8318	7.3311	71.8401	7.1343
71.83527	7.6461	71.8236	7.5657	71.8383	7.3417	71.8476	7.1422
71.84282	7.6896	71.8303	7.5837	71.8457	7.3595	71.8558	7.1789
71.85056	7.6927	71.8369	7.6077	71.8543	7.3740	71.8623	7.2122
71.85746	7.7304	71.8442	7.6243	71.8607	7.3953	71.8701	7.1884
71.86473	7.7329	71.8524	7.6558	71.8683	7.4348	71.8776	7.2051
71.87255	7.7444	71.8590	7.6954	71.8759	7.4447	71.8868	7.2275
71.88216	7.7796	71.8663	7.6770	71.8854	7.4289	71.8941	7.2141
71.88936	7.7940	71.8744	7.7178	71.8923	7.4155	71.9021	7.2199
71.89594	7.7500	71.8837	7.7130	71.8994	7.4296	71.9092	7.2513
71.90411	7.7640	71.8908	7.6803	71.9074	7.4081	73.7638	6.3379
73.75887	6.7763	71.8976	7.7062	73.7620	6.4810	73.7717	6.3356
73.76622	6.7568	71.9058	7.7225	73.7703	6.5277	---	---
---	---	73.7604	6.7847	---	---	---	---
---	---	73.7685	6.7334	---	---	---	---

Table 1. Theta-1 Orionis A Observations Data. (HJD 2,454,000+)

### 7. Data Plots

Figure 7 shows the 02 December 2006 B filter eclipse lightcurve during ingress and the 05 February 2007 partial egress.

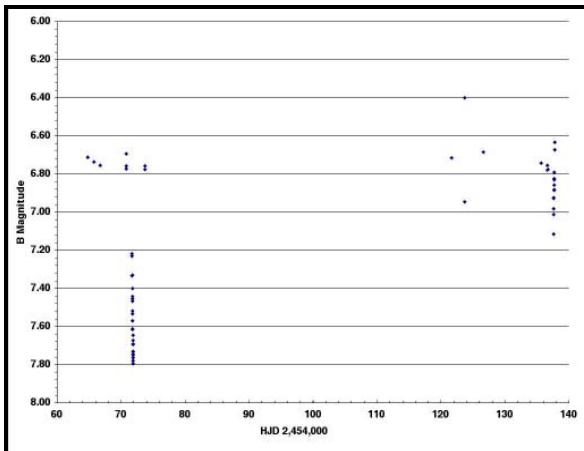


Figure 7. Theta-1 Orionis A Data Nov 2006 - Feb 2007 (B Filter).

Figure 8 shows a plot showing estimated contact times for the 02 December 2006 primary eclipse.

Event	Estimated HJD
First Contact	2,454,071.520
Second Contact	2,454,071.900
Mid-Eclipse	2,454,072.320
Third Contact	2,454,072.730

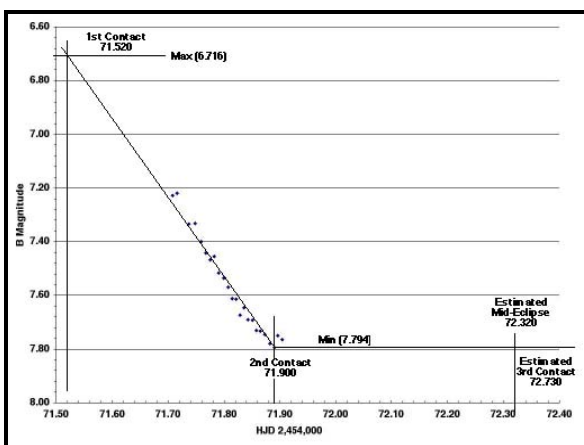


Figure 8. Theta-1 Orionis A Ingress Contact Points 02-03 December 2006 (B Filter).

Figure 9 shows a plot showing estimated contact times for the 05 February 2007 primary eclipse.

Event	Estimated HJD
Third Contact	2,454,137.185
Fourth Contact	2,454,137.760

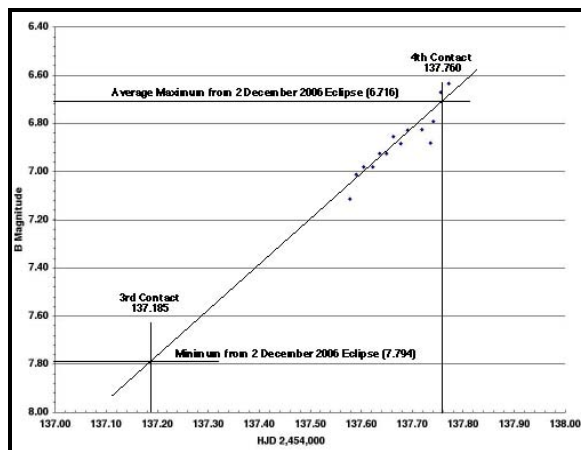


Figure 9. Theta-1 Orionis A Egress Contact Points 05 February 2007 (B Filter).

### 8. Analysis

Table 2 summarizes the observed magnitudes for the 2006-2007 observations. The Delta is the difference between the Avg Max and Min data (Min – Avg Max). The greatest magnitude change during the eclipse was in the V band (1.2279) while the smallest was in the R band (0.9969).

Filter	Max	Avg Max	Min	Delta	Published
B	6.4011	6.7157	7.7940	1.0783	6.72
V	6.5058	6.4947	7.7226	1.2279	6.72
R	6.2328	6.4478	7.4447	0.9969	6.41
I	6.0481	6.3582	7.3902	1.0320	6.20

Table 2. Theta-1 Orionis A 2006 -2007 Observed Magnitudes.

Table 3 summarizes the observed and estimated contact times for the 02 December 2006 primary eclipse. The earliest first contact was in the I band (HJD = 2,454,071.525) while the latest first contact was in the V band (HJD = 2,454,071.709). Mid-eclipse and third contacts were estimated to be the same in the V and I bands (HJD = 2,454,072.295 and HJD = 2,454,072.708, respectively). This is assuming a minimum primary eclipse time of 20 hours.

Filter	First	Second	Mid (Est.)	3rd (Est.)
B	071.652	071.900	072.320	072.730
V	071.709	071.875	072.295	072.708
R	071.535	071.869	072.289	072.702
I	071.525	071.875	072.295	072.708

Table 3. Contact Times for 02-December 2006 Primary Eclipse (HJD 2,454,000+).

## 9. Conclusions

Much was learned both about CCD photometry and the Theta-1 Orionis A star system. With the photometry system used it appears 4.0-second exposures are too long. Future observing may be done at 1.0 seconds. The 02 December 2006 data looked good, using only 0.5-second exposures. The 05 February 2007 B and I data looked good, but the V and R data was very scattered and of little value. Because the V and R data were higher counts than the B and I data leads us to believe the shorter exposure used during the 02 December 2006 eclipse is better. A compromise might be exposures of 1.0 seconds.

During the 02 December 2006 eclipse, the predicted mid-eclipse times seemed to be considerably early. The predicted time was HJD = 2,454,071.799, but from our observations, the mid-eclipse (B band) was estimated at HJD = 2,454,072.320.

Future plans are to start earlier in the next season and try to image several eclipses.

## 10. Acknowledgements

The research reported in this paper made use of the following Internet on-line resources:

AAVSO Julian Day Calculator:

<http://www.aavso.org/observing/aids/jdcalendar.shtml>

SIMBAD Astronomical Database:

<http://simbad.u-strasbg.fr/simbad/>

Smithsonian/NASA-ADS Astronomy Abstract Service: [http://adsabs.harvard.edu/bib\\_abs.html](http://adsabs.harvard.edu/bib_abs.html)

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